A Partnership for Modeling the Marine Environment of Puget Sound, Washington

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LONG-TERM GOALS

Puget Sound, Washington, is both the largest fjord in the lower forty-eight states and closest to the substantial urban centers of Seattle, Tacoma, Everett and surrounding communities. The sound has seasonally high annual phytoplankton standing stock and primary production, and they support several economically valuable fisheries. Our long-term goals are to develop quantitative understanding of the Sound's circulation and marine ecosystem, and of the sensitivity of the physical and the biological system to natural and human perturbations; and to develop models of Puget Sound that can aid agencies with responsibilities for environmental management in making informed decisions and serve as marine science education tools.

OBJECTIVES

Our partnership will develop, maintain and operate a suite of flexibly linked simulation models of Puget Sound's circulation and ecosystem, a data management system for archiving and exchanging oceanographic data and model results that are accessible to all members of the partnership as well as to the regional and oceanographic community, and an effective delivery interface for the model results and observational data for research, education and policy formulation. Our partnership will conduct scientific research aimed at developing fundamental understanding of the Sound's working, as well as addressing practical questions raised by the regional community concerning management of the Sound and its resources. Our partnership will function as an estuarine research node within the NOPP Ocean Information Commons.

APPROACH

The partnership consists of five separate organizations: University of Washington (UW, School of Oceanography and College of Education), Department of Natural Resources and Parks, King County, Washington (KC-DNR), Washington State Department of Ecology (WA-DOE), Puget Sound Naval Shipyard (PSNS)/SPAWAR, and Ocean Inquiry Project (OIP). It is administered from School of Oceanography, UW. Collectively we are operating or developing four dynamically based, predictive models of the Sound's aquatic environment, each with a different spatial coverage (and a fifth module for biogeochemistry), and our goal is to integrate these modeling efforts into a coordinated whole. Our tasks are divided as follows:

- Project coordination: Mitsuhiro Kawase (UW)
- Model operation and development:
    - Puget Sound Circulation Model: Kawase, Bruce Nairn (KC-DNR)
    - Sinclair-Dyes Inlet Model: Robert Johnston (SPAWAR), P.F. Wang (SPAWAR)
    - South Puget Sound Model: Jan Newton (UW), Skip Albertson (WA-DOE)
    - Duwamish Estuary/Elliott Bay Model: Randy Shuman (KC-DNR)
    - Aquatic Biogeochemistry Model (ABC): Allan Devol (UW), Nairn, Newton
- Data management and infrastructure: Miles Logsdon (UW), Mark Warner (UW)
- Education and visualization: William Winn (UW), Fritz Stahr (OIP)

WORK COMPLETED

Regional Workshop and Other Presentations. We held a scientific workshop for scientists at regional academic institutions, federal and local government agencies that had been in our work plan on Friday, April 23, 2004 at the University of Washington, School of Oceanography. The goal of this workshop was to present the current status of marine modeling capabilities in the Puget Sound region as well as develop and refine a subsequent research agenda. The workshop was organized into two sections. The morning session included a description of the current PSMEM status including anticipated goals and then focused on participant activities involving current, planned or envisioned modeling projects. There were two additional individual presentations by non-partnership participants (C.J. Beegle-Krause of NOAA HAZMAT team and Correigh Greene of NOAA Fisheries). The afternoon session broke out into three groups of randomly selected participants to focus attention on specific interests such as water quality, aquatic / fisheries resources, atmospheric – terrestrial – marine interaction, and hazardous materials response. In addition, the Education and Visualization Team presented the Virtual Puget Sound (VPS – a dynamic 3D visualization of model data) in both summary form and as a participatory exercise during the lunch break. A brief, concluding session by the whole group was held at the end of the meeting, and the meeting agenda and summaries of the breakout group discussions are posted on our web site.

PSMEM partnership results were also presented by Newton and Albertson at the Restore America's Estuaries meeting held at the Seattle Conference Center 12-15 September 2004.

Modeling; Model Coupling. Daily operational hindcasting of Puget Sound circulation is now done routinely, and animation result is posted on our web site. In anticipation of increased computational workload for the second half of our project, we have built a computational cluster consisting of nine Apple Xserve G5s. We are currently testing the cluster setup, and will migrate our production models to the cluster during the upcoming year.

The one-way linkage between the UW Puget Sound model and PSNS/SPAWAR CH3D model of Sinclair and Dyes Inlets is almost complete. A new numerical grid for CH3D was created to resolve all of Port Orchard Passage and Liberty Bay with the model boundaries defined at Agate Passage and Rich Passage around Bainbridge Island. One-way coupling of the models is being accomplished by forcing the CH3D model with output from the Puget Sound POM model at the boundaries for specified simulation periods. Work has also been completed incorporating the NetCDF (network Common Data Form) format to output a common data format from CH3D.

Development of the Aquatic BiogeoChemistry Model (ABC) has continued in the context of simulation of phytoplankton bloom cycles in Budd Inlet, south Puget Sound. We have completed a closest-approach model comparison between EFDC (used by WA-DOE) and ABC; these results will be available shortly as a brief report. We have come to realize limitations of the Inlet, whose dynamics is almost entirely driven from the boundary, as a test bed of the model. Accordingly, we have now implemented ABC for the entire Puget Sound Basin, using a coarse-resolution version of the circulation model as the transport model and are in an early stage of testing the model. WA-DOE is in the process of organizing boundary condition data for the year 2000 ABC run for the full-domain ABC model.

Education and Visualization. The Education and Visualization Team completed the transition of VPS to desktop PC workstations, as well as making user interface improvements. This made VPS useful for inquiry style learning for as many as 30 students at once. A paper describing a Fall 2003 study of VPS use in a college-level oceanography course has been submitted to the Journal of Research in Science Teaching. In the summer of 2004, VPS was used every day for two weeks with dyslexic children in grades 4- 6 who were attending an intensive language program at the University of Washington.

Data Collection and Management. OIP gathered in-situ field data for the Partnership on 15 separate cruises on the Sound, engaging over 200 students in the process of marine science. These cruises were funded by student fees and outside grants and donations. In August 2004, OIP contributed staff and its CTD to help collect data with the Hood Canal Dissolved Oxygen Project (HCDOP).

DOE collected hydrographic and ADCP data in South Puget Sound via a week-long cruise on the R/V Barnes from 27 September to 1 October 2004; the cruise covered approximately 80 stations and the data collected represent an end-of-summer state of the South Sound at the conclusion of a drought.

In support of the Partnership's modeling activities we have been developing a data management system that would hold database for forcing and verification data as well as model results. The database, developed using Access, has been converted to Postgres for greater power and flexibility. The database is now serving first year data of UW PRISM Puget Sound hydrographic surveys on the web.

RESULTS

Regional Workshop. The regional workshop was a great success; twenty-six scientists from regional and federal governments including NOAA, USACE, EPA, and Washington State Departments of

Fish/Wildlife Services, consulting firms, and academia participated in addition to seventeen participants from the partnership institutions. The partnership has developed a better understanding of the region's need for marine modeling, and the participants' response has given us confidence that our partnership will provide great value for the regional marine science community. Summaries of the breakout groups' discussions are now posted in the Workshop page of the PSMEM web site. There was a strong desire among the participants that this kind of workshop should be held regularly. We have not planned further workshops in our original proposal but we will consider partnering with other regularly held regional scientific conferences, such as the Pacific Estuarine Research Society and the Georgia Basin – Puget Sound conference,

Modeling. An accidental oil spill in the night of December 30, 2003 near Point Wells in the north main basin of the sound provided us with an unexpected opportunity for a lagrangian validation of the model's surface flow field. We incorporated the model flow field into the NOAA HAZMAT spill trajectory model for a hindcast of the oil spill trajectory, to compare with a visual observations of the spill made in the following day. The the spill trajectory model correctly hindcasted the southwestward movement of the spill into Port Madison (Fig. 1) although the simulation was highly sensitive to the wind forcing. Nevertheless this has given us confidence that the Puget Sound model can become a useful resource for those responding to short-term environmental accidents. The oil spill simulation was presented at the 2004 Pacific Estuarine Research Society Meeting on May 18 in Port Townsend, WA [1].

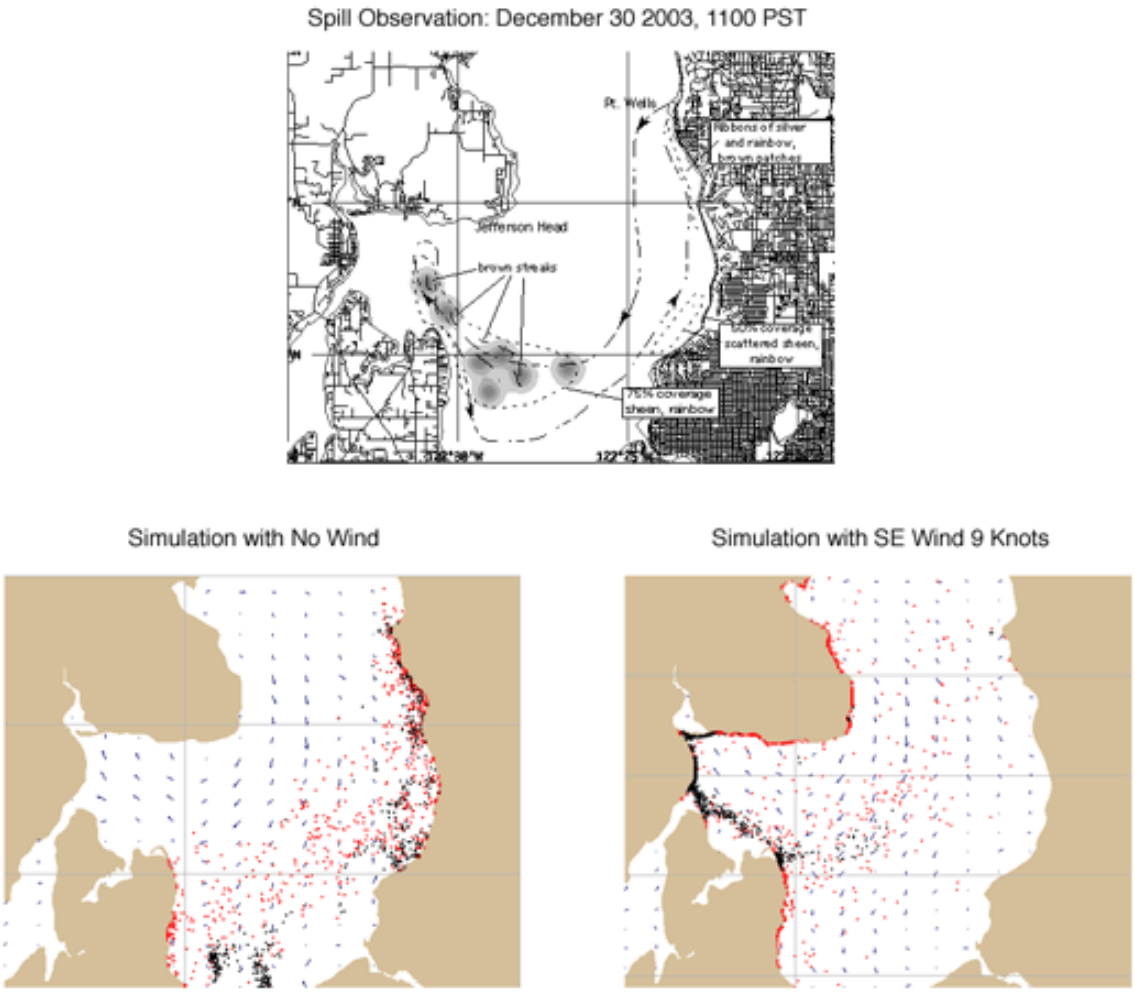

Figure 1: Comparison of an oil spill observation from overflight on December 30, 2003, 1100 PST (top) with simulations without (bottom left) and with (bottom right) wind. The dotted line with arrows in the top panel is the path of the overflight, not the trajectory of the spill.

A sensitivity analysis was conducted with the Puget Sound Circulation Model to help elucidate the factors that affect the model's velocity predictions through Possession Sound, which appear contradictory to the existing current meter data. This evolved into a comparison of the model with the EFDC model, and work is continuing on documenting the differences between these two hydrodynamic models. This work will provide a background required for linking King County's Duwamish-Elliot Bay model based on EFDC to the Puget Sound Circulation Model.

DOE's South Puget Sound model has been applied to several recent problems in more urban embayments in the region. We simulated the dilution of effluent from a Waste Water Treatment Plant near the City of Shelton (Fig. 2) at higher resolution than our original model. We have also modeled oxygen levels at depth in Budd Inlet near Olympia for longer time periods than before to look at the effects of interannual variablity (Fig. 3).

Education and Visualization. The fall quarter 2003 comparison of classes using VPS versus an in-situ field experience demonstrated that VPS can be used on a regular basis in a college class. VPS

was successful at teaching the basic concepts and principles of estuarine circulation and stratification, provided a context for students who had little prior experience with the ocean, and helped students generalize what they learned from the lecture material. The UW students in the study later used VPS while investigating the best locations for new sewer outfalls for increased populations in Puget Sound (a class exercise). The most interesting result of the study was that those who had no prior background with natural water understood concepts taught with the in-situ field experience better than those with similar background that only used VPS to learn the same concepts. While not all data analysis is complete for the study with dyslexic children, we found that they learned a great deal about tides, currents and salinity. Their language skills improved and some developed impressive three-dimensional mental models of the bathymetry of Puget Sound.

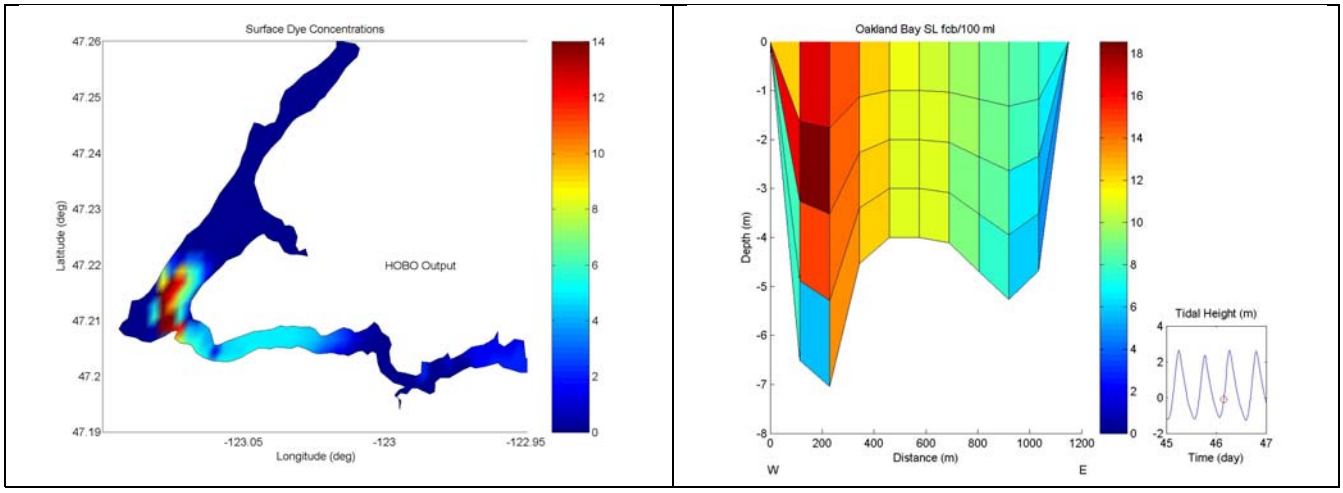

Figure 2. Plan and section views of a dye release simulation in Oakland Bay made with 50 to 200-m resolution.

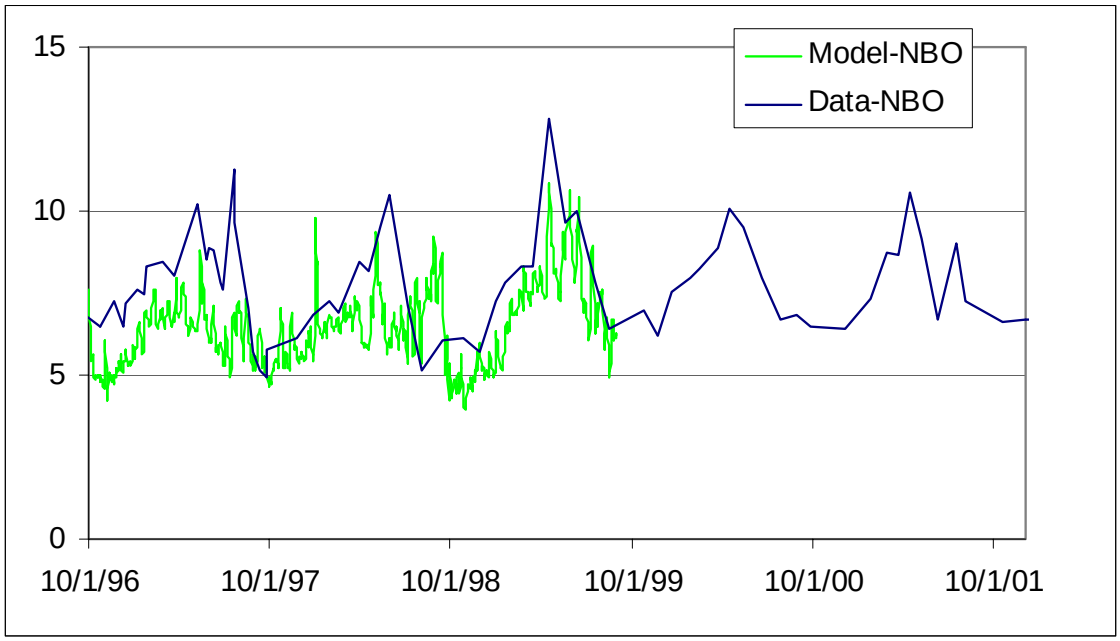

Figure 3. A multiyear simulation for near-bottom oxygen from Ecology's South Puget Sound model in Budd Inlet's inner West Bay, near Olympia with normal 500 to 600-m resolution.

IMPACT/APPLICATIONS

National Security

An improved modeling capability of the circulation and marine ecosystem of Puget Sound will help local and regional government devise procedures to deal with, for instance, chemical/biological attacks involving harmful agents that may be/need be flushed down into our marine waters, and with terrorism aimed at military and industrial installations that may result in environmental contamination.

Economic Development

Predictive modeling of Puget Sound's circulation and marine ecosystem will have positive impacts on many economic activities taking place in the Sound. For instance, forecasting of harmful algal blooms (HABs) and better understanding of hypoxia-induced fish kills in the Sound will help commercial fisheries better deal with this threat to their livelihood. Detailed knowledge of currents and hydrography will help diving operators with their underwater work. Understanding longer term variability in water quality leading to marine ecosystems change will help managers of fisheries resources make decisions.

Quality of Life

The Puget Sound region has always enjoyed a quality of life directly related to the quality of our environment. Our models provide tools for evaluating the impact of regional scale actions on the marine environment by predicting response of the latter to potential stressors. Oceanographic knowledge also has direct uses and benefits for those who work and live at sea. For instance, knowledge of currents will help Coast Guard and regional law-enforcement agencies with search and rescue operations and contaminant spill containment.

Science Education and Communication
With the aid of suitable visualizations, support material, and curriculum modules, the model results will be a valuable tool for learning about Puget Sound's marine environment that can be used in classroom settings as well as by the public at large in museums and through the web.

TRANSITIONS

Economic Development
The results of the Inlet-scale model of fecal coliform (FC) in Sinclair and Dyes Inlets are already being used by the Washington State Department of Health to reclassify shellfish beds in Dyes Inlet [2]. For the first time since 1969 commercial shellfish harvesting will be conditionally approved for parts of Dyes Inlet [3]. This would have not been possible without the significant improvements by the City of Bremerton in controlling combined sewer overflows and the ability to model FC dispersion in the Inlets [4]. The models will also be used by the Washington State Department of Ecology to establish TMDLs for the Inlets [5, 6].

Quality of Life
We are providing modeling resources in terms of expertise and computational hardware to Hood Canal Dissolved Oxygen Project (HCDOP). This collaborative project has been developed in response to concerns of residents of communities around the canal about recurrent fish kills in Southern Hood Canal in recent years, which are believed to be due to persistent hypoxia in the marine waters of this region. HCDOP has received congressional funding as well as funding from National Fish and Wildlife Foundation for FY 05 and 06 for a comprehensive study of hypoxia in Hood Canal encompassing observations and modeling of circulation and biogeochemistry of the marine waters and terrestrial inputs of fresh water, nutrients and organic matter. The project’s goals are to sort out anthropogenic changes in the oxygen level, if any, from natural variabilities, and to assess the effectiveness of proposed remedial measures. We have provided initial estimates of oxygen consumption rates using a simple box model of Puget Sound circulation ([7, 8]).

Science Education and Communication
We installed a teaching version of VPS in the School of Oceanography’s Spatial Analysis Laboratory which has been used by a number of instructors in teaching undergratduate classes. This work is still on-going, especially in terms of training and documenting curricula to be used with VPS.

RELATED PROJECTS

The partnership continues a strong cooperative relationship with Puget Sound Regional Synthesis Model (PRISM, www.prism.washington.edu), a University of Washington project to develop and consolidate University-wide expertise in natural and human environment of the Puget Sound region.

The partnership’s work compliments work being conducted under PSNS & IMF Project ENVVEST [9] to conduct modeling studies of the Sinclair and Dyes Inlet Watershed to assess the impact of CSO discharges on water quality of the Inlets [10] and support the development of TMDLs for the watershed [11, 12].

The Ocean Inquiry Project ran a workshop in March entitled “Coordinating and Advancing Field-based Marine Science Education in Puget Sound” which was funded by the Russell Family Foundation. It gathered over 80 participants together to discuss what could help further the exposure of students to marine science. The basic result was to suggest the creation (and staffing) of a coordinator position to help link providers and users of field based marince science education. A copy of the final report is available at http://www.oceaninquiry.org/workshop.

As described above, partnership scientists will play an active role in the Hood Canal Dissolved Oxygen Project.

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PUBLICATIONS

Babson, A., M. Kawase and P. M. MacCready, Seasonal and Interannual Variability in the Circulation of Puget Sound, Washington: A Box Model Study, submitted to *Atmosphere-Ocean*.